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Optical Fiber Technology 2012

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***Abstract*—The Conference on Optical Fibers and Their Applications, Nałęczów 2012, in its 14th edition, which has been organized since more than 35 years, has summarized the achievements of the local optical fiber technology community, for the last year and a half. The conference specializes in developments of optical fiber technology, glass and polymer, classical and microstructured, passive and active. The event gathered around 100 participants. There were shown 60 presentations of 20 research and application groups active in fiber photonics, originating from academia and industry. Topical tracks of the Conference were: photonic materials, planar waveguides, passive and active optical fibers, propagation theory in nonstandard optical fibers, and new constructions of optical fibers. A panel discussion concerned teaching in fiber photonics. The conference was accompanied by a school on Optical Fiber Technology. The paper summarizes the chosen main topical tracks of the conference on Optical Fibers and Their Applications, Nałęczów 2012. The papers from the conference presentations will be published in Proc. SPIE, including a conference version of this paper. The next conference of this series is scheduled for January 2014 in Białowieża.**

***Keywords*—lightguide, optical fiber, photonics, optical fiber photonics, optoelectronics, optical fiber technology, optical fiber glasses and polymers, active optical fibers, photonic optical fibers, microstructured optical fibers, microoptics, photonic materials and metamaterials, fiber lasers**

I. Introduction, a Cycle of OFA Conferences

THE cycle of OFA Conferences on Optical Fibers and Their Applications is held in this country since 1976. Now they are organized every 18 months in changing locations in Białystok and Białowieża interleaved with Lublin and Nałęczów. Dominating topics during the Białowieża research meetings are wide applications of optical fibers and associated optoelectronic and photonic systems. Nałęczów meetings (previoulsy held in Krasnobród) are focused on photonics materials engineering, technologies, construction and theory of optical fibers. The conference is organized by Białystok University of Technology (Faculty of Electrical Engineering) – in Białowieża, and UMCS (Laboratory of Optical Fiber Technology) together with Lublin University of Technology (Institute of Electronics and Information Technologies). The sponsoring organizations for this conference are: Committee of Electronics and Telecommunications of Polish Academy of Science, Polish Optoelectronics Committee of the Association of Polish Electrical Engineers, and Photonics Society of Poland. Conference presentations are traditionally published in the Proceedings of SPIE, but also in Elektronika Journal by SEP [1]–[100]. The bibliography published by this conference is relatively rich and shows quite extensible achievements of the optical fiber research and technical community of optical fiber photonics in this country and this geographical region, including guests publications from eastern neighbors of Poland like Ukraine, Belarus, but also from Kazakhstan.

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The Conference on Optical Fibers and Their Applications, Lublin-Nałęczów 2012 has gathered around 100 participants. There were presented together 60 papers from around 20 technical and research centers and a few research firms spanning the whole country and neighboring region. The conference was richly attended by young researchers, adepts in optical fiber photonics. The organizers of the conference were prof. Waldemar Wójcik of Lublin University of Technology (Chair of the Conference Scientific Committee) and dr Paweł Mergo of University of Maria Curie-Skłodowska in Lublin (Secretary of the Conference Scientific Committee, and Manager of The Optical Fiber Technology Laboratory at the Faculty of Chemistry at UMCS). This paper is a digest of some chosen and main topical tracks of the XIVth Conference and IIIrd School on Optical Fibers and Their Applications, Lublin-Nałęczów 2012. This cycle of conferences, together with such meetings of the local technical and research photonics communities as: Symposium on Laser Technology (held every three years in Świnoujście), Optoelectronic an Electronic Sensors, WILGA Photonics Applications and Web Engineering, Integrated Optics by Silesian University of Technology, Polish-Czech-Slovak Conference on Optics, and some others, create a major and open forum for this topical area in this country and geographical region. Recently, similar fora are created by large European, infrastructural research projects, within the FP7, in the area of photonics. One of such big projects, reaching nearly 20ME is Labs/Warsaw and FOTEH. They are coordinated by Warsaw University of Technology (FE&IT).

II. Optical Fiber Polymers, Photonic Materials and Metamaterials

Polymer optical fibers have broad and swiftly extending areas of applications in short distance communications, building of passive and active functional photonic components. The basic material for polymer optical fibers is PMMA. The polymers and polymer optical fibers are researched in ITME/Warsaw, and UMCS/Lublin. At UMCS, Faculty of Chemistry, there are carried out porozymetric and thermoanalytic investigations of linear polymers of very good optical properties. There are researched processes taking place during PMMA polymerization on the basis of analysis of the value of the proper surface of mezo-pores and decrease in the sample mass with the increase in process temperature. The aims of the research are: ultra-purification of input substrates for optical fiber polymers, avoidance of substrate, process and product recontamination, understanding of contamination transfer during the process of polymerization, mastering of technology of optical polymers and plastic optical fibers, lowering of optical losses in polymers, mastering of effective refraction changes in optical fiber polymers, pulling of optical fibers of designed structure (classical, microstructured, doped, impregnated, etc.), mastering of technology of ultimately regular, non-distorted polymer photonic optical fibers.

Photonic crystals are periodic, refractive optical nanostructures, with the aim to influence the movement of photons in a similar way the periodicity in semiconductor crystals are influencing the movement of electrons. Photonic crystals feature a photonic band gap. Allowed and forbidden directions of light propagation are determined by diffractive phenomena. This feature is a cause of such phenomena as inhibition of spontaneous light emission from a source, existence of lossless mirrors reflecting light in all directions, and low loss propagation of light beam along the allowed direction of propagation determined by the photonic crystal axis and by the dimension of the allowed band. The characteristic dimension of a photonic crystal is comparable with half wavelength of propagated light. (i.e. 200 – 800 nm). A Bragg grating is an example of an isotropic, single dimension photonic crystal (photonic bandgap is in one dimension). Anisotropic Bragg gratings work as optical keys. Single dimensional crystals are used in thin film optics. A holey optical fiber is an example of two-dimensional photonic crystal. These fibers are used for research on nonlinear propagation effects and guidance of wavelengths outside the transparency band of the fiber material. The work on microstructural optical fibers and photonic crystals are carried on in ITME and UMCS. The interest is also in nonlinear photonic crystals.

Optical metamaterials is a class of materials designed for direct interaction with waves starting from terahertz (millimeter and submillimeter waves), via the IR up to visible. The periodic structure of the material is performed from individual, resonant nano-cavities, which exchange energy with a passing-by photon. Characteristic dimension of an optical metamaterial is of the order of single nano-meters. The structures of metamaterial (meta-atoms) react to photons analogously like atoms and ions. Small size of the characteristic dimension makes metamaterials homogeneous. They exhibit artificial magnetism for optical frequencies, differently to classical materials. This leads potentially to materials of negative refraction in optical domain. Research on metamaterials for photonics are carried out at UW, ITME and some other places.

III. Active Optical Fibers, Fiber Amplifiers and Lasers

Optical fiber lasers, are to some extent competitors, and in other sense, a supplement of semiconductor lasers. Semiconductor laser must be, in majority of cases, coupled to an optical fiber. The coupler has a confined value of the energy efficiency. An active optical fiber, which is a key component of an optical fiber laser, is in a natural way, and almost lossless, coupled to a transmission fiber. The power generated in optical fiber lasers is now considerable, what means that it is comparatively easy to cross the threshold of fiber nonlinearity, in a single mode glass optical fiber. The quality of the fundamental mode is high and there is usually no need to extract the single mode beam out of the fiber. To build a fiber laser, classical filaments are used, as well as microstructural, from photonic crystals. A similar situation is in the domain of semiconductor lasers. They can be manufactured in a classical way as a heterostructure, or from a microstructured semiconductor. Keeping the state of polarization in a fiber laser requires the usage of a polarization maintaing optical fiber. Active polarizing optical fibers can be optical or photonic, made of classical glass or polymer, photonic crystal or a metamaterial. Such optical fibers passive and active, optical and photonic, glass and polymer, made for building various kinds of optical fiber amplifiers and lasers, are manufactured my MCVD and preform assembly in the Laboratory of Optical Fiber Technoloft at the Faculty of Chemisty of the UMCS in Lublin. Polymer, microstructural optical fibers are used to build optical fiber lasers at Wrocław University of Technology and at some other technological centers of optical fiber photonics in this country (Białystok, Warsaw). Photonic Optical fibers with full (filled) core are manufactured by positioning a regular set of capillaries around a doped core preform rod. The active core is done by a classical MCVD method, supplemented by a process of wet doping with rare earths, typically with erbium or/and neodymium. Addition of Al_2O_3 prevents the effect of unfavorable active ion clustering in the host glass. If the fiber is to serve for writhing a Bragg grating, it is doped additionally by GeO_2. Some of fibers may be hydrogenised. A considerable increase of the refraction in a doped core in such a way is compensated for by the doping of fluorine. The final value of refraction to be obtained is close to an average core refraction which is near to the value for pure silica glass. Active photonic fiber may be manufactured as polarization maintaining by positioning of stress members at both sides of the active core.

Characterization of active optical fibers embraces calculations and measurements of active cross sections for the absorption and emission. The spectra are measured by fiber oriented typical spectroscopic methods. Additionally, the emission spectrum may be measured by the usage of a broadband light source. Standard active optical fibers have emission spectra in telecommunication windows (bands). Sensors oriented, but also microstructural, optical fibers may heve emission spectra in different regions, like visible and/or MIR and FIR. Active telecommunicatin optical fibers are pumped typically by a laser diode (or several laser diodes) for the wavelength of 980 nm for erbium doping, and 808 nm for neodymium doping. The measured absorption spectra are approximated by the Spline or Gauss type functions (or other ones). The classical, but simplified Ladenburg – Fuchbauer method is used to calculate the active cross sections. Optical pump should provide a signal which covers maximally the spectra region of the absorption band. Pumping effectiveness is measured by the coverage integral. To calculate the active cross sections for absorption and emission, the following data are needed: parameters of the active cross sections for absorption and emission, active dopants concentrations and distribution, and life time of the inversion state. The coverage integral is a function of wavelength which depends on the active dopant.

The coverage integral may be optimized in different directions, for example to measure and make its non-dependence on the wavelength (spectral immunization), or just oppositely to make this function very spectrally selective, or to make this characteristic of a spectral discriminator type, of a type of low band or up band spectral filter.

An optical fiber laser may work in different configurations of its resonator: internal, external, loop. etc. The loop configuration has a length of fiber configured as a loop with WDM multiplexer and demultiplexer, optical isolator, and optionally, for example polarizer, polarization controller (or any other inserted component compatible with optical fiber, like graphene layer, etc). The optical circuit is powered by an optical pump and its work is evaluated by an optical spectrum analyzer – OSA. Internal polarizer enables setting and precise tuning of the generated wavelength, in the range of a fraction of nm. A thin film graphene component (used as a saturable absorber), attached to the end face of an active fiber, it is possible to coordinate the modes during a pulsed regime of laser work. Research work on microstructured active optical fibers and construction of fiber lasers are carried out at Wrocław University of Technology (prof. E. Bereś-Pawlik).

IV. Photonic Optical Fibers – Nematic and Smectic Ferroelectric

Photonic optical fibers, microstructural, are made of glass or polymers. Microstructural construction, in a form of a two dimensional matrix which builds the structure of a photonic crystal, is a basis of photonic bandgap limited propagation of the EM wave in the fiber. A defect in the structure, filled or empty, is localized as a core. There are two distinct propagation mechanisms, which can be switchable in a photonic crystal optical fiber impregnated with liquid crystal. Propagation based on modified method of effective refraction relies on that the integrated refraction from the whole propagation area is bigger than in the area of the evanescent wave (the area of microstructure matrix). In the photonic method of propagation, the area of propagated wave has lower refraction than the area of the evanescent wave – which is the area of the microstructure. The direction of allowed propagation is indicated along the fiber axis by the Bragg diffraction mechanism – the existence of a prohibited photonic bandgap effective in all other directions but fiber axis. Classical photonic optical fibers are not filled – they are empty. In a sense, that the microstructure is not filled. But they may be filled with gases or liquids for sensing or optical effects, which define additional functions of such fibers. Filling a holey optical fiber with a liquid crystal of ferroelectric properties makes this fiber highly susceptible to external reactions of electric fields ,magnetic fields, temperature, pressure and mechanical perturbations, as well as polarization of propagated or external light. Research on microstructural optical fibers combined and/or connected with liquid crystal holey fibers is carried out at the Faculty of Physics of WUT (prof. T. Woliński, prof. A. Domański). Dynamic functional phenomena are possible in such fibers, involving propagation and polarization states. This is due to a short reaction time of nematics to the external E field. The involved phenomena may be: change of the propagation mechanism from optical to photonic and vice versa, possibility to propagate and tuning photonic bandgaps in the transmission spectrum of the nonlinear fiber, dynamic filtration, fast tunable attenuation characteristic, tunable retardance – phase delay between orthogonal polarization components of the propagated fundamental mode.

A bright positive future in an application sense, is foreseen for planar and 3D (or rather multi-planar) structures built of photonic crystals. The most important feature of these structures seems to be the possbility to guide single mode light beam in a lossless manner (or with very low losses) along an arbitrary complex, and obviously not linear, path including dense and sharp two and three dimensional curvatures. Tunability of such structures, by optical, electrical and mechanical means, at a cost of of some increased excess losses, is provided by impregnation of these structures with low-loss liquid crystal of fitted refraction, or with other optically active materials, or generally electromagnetically active. Initially, microstructural optical fibers and other photonic structures (couplers, attenuators, Y structures, modulators, etc.) were impregnated with nematic mixtures. Now, there are widely used smectics of ferroelectric properties and chiral materials. Impregnation of a microstructural fiber (or other photonic structure) with ferroelectric fluid of high refraction (the level of refraction is referred in such cases to a pure silica glass) causes generation in the material a tunable photonic mechanism of light propagation. Electric tuning is much faster in the case of application of smectics in optical fiber than nematics. Thermal tuning is also more effective. Ferroelectric liquid crystals in the smectic phase have high viscosity. The impregnation has to be performed in high temperatures, around 150°C, in the isotropic phase of the substance. A drawback of the experiments with ferroelectric optical fibers is the necessity to apply high modulation voltages for tuning of the spectral characteristic of the fiber, nonlinearity and hysteresis of the tuning characteristic. The work is carried out at the Faculty of Physics, WUT.

One of the researched functional photonic components done on the liquid crystal fiber is a tunable, fully optical fiber polarizer. Such a polarizer was build at the Faculty of Physics WUT. Retardance tunability was achieved in the range of 0 – 15 λ, what means phase tuning in the range 0 – 30 π. Phase modulator was controlled electrically by means of two electrodes and a signal with amplitude modulation. Fast switching time was obtained by elimination of a slow relaxation phase of the liquid crystal molecules to the initial state. Phase tuning by a single period of the wavelength (2π) was obtained during time period shorter than 40 ms. Phase change is a function of the control voltage, which opens up the possibility to build a fully fiber optic of polarization state controller. Full control of polarization state requires the possibility to change the retardance very fast in the range of 0 – 2π. This involves application of three successive lengths of optical fiber with alternant configuration of the electrodes, in which there is possible retardation tuning in the range of 0 – $\pi/2$. The axis of birefringence of the middle fiber length is rotated by $\pi/4$ against the birefringence axis of the first and the third lengths. Large flexibility is obtained in the system in which it is possible to tune the retardance in a wide range. There was performed a control system of the optical fiber polarizer with four electrodes, of pairs rotated against each other by $\pi/4$.

V. Planar Optical Waveguides and Photonic Integrated Circuits

Many of the solutions of photonic sensors and functional components base on planar optical waveguides, working in the geometry of modal differential interferometers with single optical channel. The basic work parameter for such photonic components is model birefringence of the waveguide. Measurement of birefringence requires excitation in the waveguide both orthogonal modes TE and TM, which have very similar propagation constants. Phase difference between orthogonal modes TE and TM is a function of the value measured by such sensor. Measurement system consists of input beam polarizer, coupling prism, polarization analyzer and a CCD camera. It performs the analysis of the dissipated light, and from the distribution of intensity of this dissipation determines the birefringence by the method of polarization interference. Transmission methods base on determination of the effective modal refractions for particular modes. The state of polarization of a beam may also be measured after leaving the fiber. Interference pattern is measured and its changes in the far field of the fiber. Beating length is determined by means of excitation of single orthogonal mode and moving point perturbation along the fiber. Dissipation method may be used in reference to planar waveguides of moderate losses. It is difficult to excite both orthogonal modes of the fundamental mode simultaneously in waveguides of a big birefringence, thus, of potentially big sensitivity to external reactions. The work on planar optical waveguides is carried out at Chair of Optoelectronics at Silesian University of Technology.

A photonic integrated circuit (PIC) is an analog to an electronic LSI/VLSI integrated circuit, in which there are combined many photonic (optoelectronic, electronic) functions on a single monolithic or hybrid substrate. Functionality of the circuit is realized on THz and optical waves extending from THz, via IR to visible and typically in the range 400 – 1700 nm. One of the obstacles at the development path of PICs was quantum noise, which prevented generation of light in the silica. Now, the PICs are manufactured on GaAs, $LiNbO_3$, etc. The applications embrace areas of optical communications, sensors, and optical computing. PICs are subject to several development tendencies like functional integration with VLSI circuits. The work on integrated photonic circuits are carried out, among other places, in IMiO PW and PWr. Current solutions include integration of a few functions like: modulation, amplification, attenuation, signal fitting, transmission channel switching, channel separation, multiplexing and demultiplexing, interferometry, sources and detectors, filters, mirrors, etc.

VI. Photonic and Optical Fiber Functional Components and Sensors

Optical fiber interference phase demodulator is working in the configuration of the Young interferometer with a split two-segment photodetector positioned on the Fourier plane. The main construction parameters of the demodulator are: distance between photodetectors, optical wavelength, sources apertures, focus length of the Fourier lens. The aim of works carried out at WAT is building of an all fiber homodyne phase demodulator, where the point sources are end faces of optical fibers with collimators. The system has large precision of phase measurement and is subject to construction optimization to lower (minimize) the error of phase measurement. A diffraction Airy image, modulated spatially, is obtained on the image plane. Differential signal from the detectors includes information on the phase difference. The error of phase determination in this circuit is analyzed by adding additive Gaussian noise to the detected signals.

An optical fiber capillary filled with a liquid crystal (of nematic mesophase) is susceptible to interaction with electrical and magnetic fields). By using external magnetic field, there were created changes in the refractive index profiles of the optical waveguide. The profile was tuned from a step index to a gradient one of different slope and numerical aperture, on a pedestal of a step-index profile. Simulation research on liquid crystal optical fibers are carried out at Rzeszów University of Technology in cooperation with Lwów University. The aim or the work is, among others, a construction of an optical fiber capillary tunable GRIN lens. The lens is expected to serve for switching the signals between multimode optical fibers, for signal distribution in local are networks.

All optical fiber interferometers are used for building optical fiber sensors. Advantage of this solution is high sensitivity and selectivity of such devices in the real field work conditions. A team at Lublin University of Technology is working on a fiber distortion sensor incorporating a birefringent photonic fiber, Sagnac interferometer and a broadband light source. Optical fiber loop of large birefringence is subject to a distortion. Polarization controller is incorporated in the loop. The controller provides maximal contrast of the spectral image. The shift of the output beam from the sensor is measured by an optical spectrum analyzer.

VII. Optical Fiber Bragg Gratings

Many of optical fiber functional components are using Bragg gratings written directly on the fiber. Depending on the construction of the grating (short-period, long-period, short, long, continuous or concatenated, skew, tapered, chirped, permanent, erasable, deep, shallow, apodized, with refractive pedestal, refractively matched, etc) they fulfill different role/function as: filters, distributed mirrors, mode mixers, energy radiators, beam concentrators, optical isolators, components of optical circulators, shapers/equalizers of spectral characteristics of optical fiber amplifiers, etc. Optical fiber gratings are manufactured in various qualities and quantities, researched, characterized, technically processed and prepared, and made available for other research teams by a Fiber Optics

Laboratory at ISE WUT (doc. K. Jedrzejewski), in cooperation with IMiO PW. The fibers are manufactured using classical singlemode telecom class optical fibers after their hydrogenation. Specialty optical fiber gratings OFG are manufactured using specialty optical fibers, polarization maintaining fibers like PANDA, microstructural fibers. OFG are written also on tapered optical fibers, on fiber couplers and other fiber components. Making a grating on a coupler makes it spectrally selective.

Skew Bragg gratings on an optical fiber are used for flattening of complex spectral characteristics of optical fiber EDFA amplifiers and for building optical fiber sensors. The plane of periodic changes of refraction is skew against the long axis of the fiber. The propagated beam is subject to partial reflection out of the fiber aperture. This part of optical power excites cladding and radiation modes. The fiber is used as a refractometer, evanescent wave sensor, tensometer, polarimeter, etc. The fiber exhibits increased sensitivity to external reactions and distortions: refractive, thermal, EM, acoustical and ultrasound, mechanical – like macro and micro bending, torsion, and stretching. Spectral characteristics of the component depend on the skew angle of grating fringes, and on the refraction of the surrounding environment (refractive background). The spectral characteristic of skew grating fiber component is typically extended from the side of shorter wavelengths than the Bragg wavelength. Radiation and cladding modes appear for both directions forward and backward. In a certain range of the background refraction, characteristic parts of the fiber transmittance change -quasi-linearly. This feature is used for building of simple refractometers for chemical analytics. Skew optical fiber gratings, for the skewness of the order of a few degrees, are made by phase mask scanning technique.

A method of optical reflectometry in the frequency domain OFDR is used to characterize classical, modified and specialty fiber Bragg gratings. This method is characterized by large spectral and space resolution. It allows to measure precisely the distribution characteristics of backward wave reflection from the photonic component in the function of its length. The OLCR and OFDR measurement methods of spectral characteristics of photonic components, including optical fiber Bragg grating filters are alternative to a method using optical spectrum analyzer OSA equipment. Connecting several OFG components in series of similar Bragg wavelength makes it difficult to measure such a complex component by an OSA module. The OFDR measurement method dominates here evidently. It allows to distinguish between individual subcomponents, measure their individual wavelengths, precise determination of grating length and its location against the far fiber end, etc.

VIII. Optical Super Continuum

Optical microstructural fibers are used, by initiation in them several coupled nonlinear effects, to widen essentially the transmitted optical spectrum. The result of coupled processes is generation of a supercontinuum in a fiber (or considerable widening of transmitted spectrum). The widening is from a virtually monochromatic or narrow-band IR signal to an exemplary typical bandwidth covering the range of 0,5 – 1,6 μm. Many of the individual involved nonlinear effects are well understood and described separately. A breakthrough was when the interaction of these individual effects was understood, described and successfully modeled, to result in a generation of a supercontinuum in the fiber. The involved and coupled effects include: phase self-modulation, four wave mixing, and solitons dynamics. Highly nonlinear optical fibers of classical optical and photonic construction, i.e. their parameters, may be optimized for generation of wide and homogeneous supercontinuum, embracing the visible and the NIR spectral ranges. There are considered three areas/methods of supercontinuum generation. These are: splitting of a soliton, modulation instability for changed pumping conditions, and pumping in the area of normal dispersion (as opposite to the region of fiber abnormal dispersion). Two first methods require fiber work in the area of abnormal dispersion. Pumping in the area of abnormal dispersion is more efficient for supercontinuum generation in a fiber.

The fiber is excited with a pumping soliton of high order in the mechanism of soliton splitting. It is a femtosecond pulse of well over the threshold power. It immediately widens and falls apart to fundamental solitons. During the “fissure” of the pumping soliton the excess of energy is dissipated in a form of dispersive waves at the short wavelength side of the spectrum. Fundamentals solitons are subject to intrapulse Raman dissipation in the long wavelength part of the spectrum. The Raman long wavelength part of the spectrum interacts with the short wavelength part via four wave mixing and cross phase modulation. Dispersion waves may be coupled again to the propagated soliton, when the phase condition is fulfilled for the group velocities of the involved waves. This leads to further widening of the spectrum in the direction of short waves, beyond the pure mechanism of dispersive waves generation.

For the mechanism of nonstability modulation, the fiber is excited with a CW wave (or quasi CW), over the threshold in such a way that there is generated in the fiber, by noise processes, a train of fundamental solitons. Long wavelength part of the supercontinuum is generated in the same way as for splitting of a high order soliton by the self-shift of the frequency (Raman dissipation). Generation of the short wavelength band stems from four wave mixing but only for the power excess in fundamental solitons. When there is no excel power, in the quasi CW work conditions – i.e. when the pumping pulse is long, then the dissipation is mainly in the short wavelength direction. When the pumping pulses are short then, the self phase modulation leads to the temporally coherent spectrum widening. In the case of longer pulser, the Raman dissipation dominates. Raman dissipation mechanism generates Stokes waves till the region of zero dispersion, where the Raman supercontinuum is created.

Optical fiber supercontinuum generator, in combination with tunable system of filters (tunable are wavelengths and width of transmitted band), is a perfect light source (carrier – narrowband and power – wideband) for transmission and telemetric optical fibers systems and circuits. Now, without such a high power and widely tunable source (or better a few of them) in the photonics laboratory it is simply impossible to work. Such sources are easily available commercially in numerable technical varieties. Despite of this, the neat phenomenon of supecontinuum generation in an optical fiber is still interesting to this degree, that in many laboratories in this country and region, there are carried out investigations, in particular with the application not necessarily classical optical fibers but microstructural ones – photonic. The generation of supercontinuum is associated with cascaded increase of several mutually combined nonlinear phenomena. This self amplification process has to end in a saturation state, because if there is no saturation level, the energy dissipation process inevitably leads to thermal destruction of the fiber (overheating and melting). The initiation level for supercontinuum generation depends on the natural nonlinearity of fiber material, fiber dimensions, field concentration in the core (measured by modal field area). Strongly nonlinear fibers, additionally with small modal area, are here advantageous, because the initiation level in a pure silica glass fiber has this level very high. High level of initiation exists in classical singlemode telecom grade optical fibers. Highe power is required to initiate supercontinuum and it should be more precisely controlled not to allow fiber destruction. The work on supercontinuum generation, control, and fiber optimization for supercontinuum generation is carried out at WAT and PW. Microstructured optical fibers optimized for generation of supercontinuum are manufactured at UMCS in Lublin and ITME in Warsaw.

Control of supercontinuum generation, in a microstructured optical fiber, is associated with optimization of chromatic dispersion for different geometrical parameters of the microstructure. Dispersion influences particular nonlinear effects in a different and quite individual way way. Dispersion also influences the coupling strength and direction/selectivity between the nonlinear effects in optical fiber. Interferometric measurement methods of chromatic dispersion allow for characterization of short lengths of fiber with great accuracy. To generate supercontinuum, there are used short lengths of optical fibers, and such lengths should be characterized and optimized. Dispersion modeling, particularly around its zero value, and being in agreement with the measurements, allows for optimization of the technological process of the fiber, to increase the efficiency of the spectrum widening processes, in a sense of energy transfer efficiency from the pump and stability of wide spectrum generation. The work on modeling and simulation of supercontinuum generation in nonlinear optical fibers (especially microstructural ones) are carried out at the Kielce University of Technology (dr T. Kaczmarek).

IX. Soliton Transmission in Optical Fibers

Existence of soliton (solitary) solutions in optical fiber was suggested in 1973 by A. Hosegaw from AT&T, as a balanced solution, a compromise between self-modulation of phase and abnormal dispersion. The solitons may be spaxce (nonlinear effect compensates diffraction) or temporal (nonlinear effect compensates dispersion, for example, nonlinear Kerr effect balances the dispersion of the group velocity). Classical solitons have scalar polarization component. A vector soliton (space and temporal) is a wave which has many (at least two) coupled components. The components of a vector soliton co-propagate together in a birefringent optical fiber due to the cross phase modulation and a coherent energy exchange between the orthogonal components. The vector solitons are polarized elliptically (opposite to scalar solitons which are polarized linearly), due to the difference in the intensities of the components. The components of a vector soliton may show four waves mixing in a nonlinear optical fiber. The solitons in optical fibers are quite well described by Manakov equations. These equations are derived from Maxwell equations converted to cylindrical coordinates with taking into account the boundary conditions typical for a single mode optical fiber at the presence of natural and always existing birefringence. At such conditions, there are obtained coupled nonlinear Schrodinger equations. Application of an inverse dissipation transform (a standard method of solving of nonlinear partial differential equations, which is a procedure analogous to Fourier and Laplace transforms) to these equations leads to Manakov equations.

One of the possibilities for trunk, singlemode optical fiber transmission is usage of solitons. First observations of solitons in a fiber were done in 1980 by R. H. Stolen, L. F. Mollenauer, J. P. Gordon. In 1986 there were transmitted soliton pulses for 4000 km using Raman effect for their amplification. In 1991, in Bell Lab, there was transmitted a data stream at the rate of 2,5 Gbps for 14000 km with the usage of EDFA amplifiers. In 1998, in Telecom France there was obtained soliton transmission at the rate 1 Tbps. These results were not, however, reduced to practice, due to the soliton nonstability effect. These effects include Gordon-Hauss jitter and Gordon-Mollenauer effect. Jitter compensation (twitter and coupling, amplification of phase noise due to fiber nonlinearity) of the solitons is complex and is not afforded in the telecommunication systems. Due to this fact, the coherent soliton transmission remains as a laboratory curiosity. A hope is awaken by transmission of vector solitons (of many or at least two mutually coupled polarization components) in birefringent optical fibers. There are researched scalar and vector solitons of the higher order and their polarization states. Dark solitons are more difficult for practical usage, but are more stable and resistant to losses.

X. Polymer Microstructural Optical Fibers mPOF for Transmission

Polymer, photonic optical fibers of a big core, confined modal dispersion, and large resistance to bending losses, working n the infrared, are considered for applications in the user access networks, like FTTH/FTTX. Such fibers are designed and manufactured in ITME Warsaw and modeled, simulated and characterized in IMiO PW. A fundamental obstacle in the usage of multimode polymer optical fibers, in access links and structural cabling of buildings (or at the user site) is attenuation and dispersion. The hope to solve this is application of polymer microstructural optical fibers to lower the number of transmitted modes, and lowering the losses by fluorination and deuterination of the polymer. There were modeled optical fibers of various distribution of the microstructure in fiber cross-section with hexagonal mode of micro-holes. There were introduced micro-holes of increased and decreased diameter. A ring of (single or double) larger holes introduced a refractive micro-trench around the core defect in the photonic structure. For a single ring of larger micro-holes, the model exhibited decreased losses for increasing net constant and increased filling factor for external holes. Additionally, for such a thick core microstructure, there were determined possible areas of low-mode and single mode work regimes. There were simulated bending losses as functions of the filling factor of internal increased micro holes. External holes immunize the fiber against the bending losses for small bending radiuses. Simultaneously, with the increase in the diameter of micro-holes, the number of propagated modes increases. A compromise is needed: singlemodedness versus low-modedness and bending losses. Bending losses show big sensitivity to the filling factor of the internal micro-holes. For a double layer of increased internal micro-holes, a fiber is obtained with increased resistance to bending losses at only a small influence on the modal structure.

XI. Optical Fiber Transmission

An essentials question asked in the WDM technology is whether transmit faster or denser? The granulation of transmission bandwidth in optical fiber UDWDM access network has to be obviously much narrower than in the transport networks. Transport networks base on channels of very big throughput. Access networks have to possess a large number of channels of a moderate throughput. But, the numbers understood today as moderate throughput and the division line between the networks of various categories change with the development of technologies. Now, the access systems may be available with 1Gbps per user with a single color light path. In the not so distant future (probably sooner than later) the throughput available for a user will be 10Gbps. The construction of very dense access networks is associated with several construction and technological issues. The most cost effective are passive optical networks, or PONs. Active networks provide, however, much bigger topological freedom, but at much larger cost. The issues of fundamental meaning in the UDWDM networks are: properties of optical channel, selectivity and stability of optical components, laser stability, minimization of the distances between the channels to a level below 3.125GHz, or around 1,6 – 0,8 GHz, keeping stable optical separations between channels (for example by application of a single laser and a stable frequency circulator circuit with frequency shifter for generation of optical carrier frequencies), and equal power in channels, keeping low power in channels, preventing non-linear phenomena including FWM, and maximization of the transmission length on the standard single mode optical fiber, and some others. Simulation experiments for such systems are carried out at the WEiT Poznań University of Technology (A. Dobrogowski, J. Lamperski). The results of experiments univocally show the advantages of UDWDM access networks. Nonlinear effects in such networks were researched, starting with the reference power in the transmitter equal to 1 mW. The FWM products were then at the level of around 45 – 75 dB below the level of the transmission channels. Increasing the power of 2o dB causes the increase in the side frequency bands to the unacceptable level of 10 dB below the level of useful channels. The UDWDM systems may be soon applied in the user networks.

The photonics laboratory at ZUT Szczecin University specializes in configuration of test transport optical fiber networks, working in telecommunication bands. There is used Alcatel Lucent hardware. It is possible to tune transponder channels inside the C band according to the ITU-T standard. To build a network there were used 8 nondependently tuned transponders of the throughput 10Gbps. A single mode optical fiber was used of Corning 28e^{+} of G.652D standard and 140 km in length. The transmission channel featured EDFA amplifiers, optical fiber chromatic dispersion compensation modules, and input and output tunable optical fiber multiplexer of the add/drop type TOADM. The maximum length of served transmission line was 340 km. The possibilities of the extended stsrem are: 88 channels in the C and L bands of maximal throughput 3,2 Tbps.

XII. Optical Fiber Technology School/Workshop by UMCS OFT Laboratory

Optical Fiber Technology Workshop was organized, for the third time, together with the conference, at the OFT Laboratory of Faculty of Chemistry of UMCS in Lublin (dr P. Mergo). The workshop is aimed at students and ph.d students realizing their work in the area of optical fiber photonics. A very valuable aim of the workshop is to show to the research students the possibilities and practical confinements of fiber manufacturing. Various kinds of optical fibers can be manufactured at the OFT laboratory at UMCS. The laboratory has also some workshop for manufacturing of optical fiber components and optical fiber cabling facility. Real participation of the students in the fiber manufacturing process has an extremely valuable value for them and for their further research work in photonics. Nothing can replace practical exposition of the students to the real technology of the components they use in their everyday research work.

XIII. Teaching Photonics

The conference was finished with an extended, traditional session and panel discussion on teaching in photonics at the universities. The session was chaired by prof.T.Woliński from Faculty of Physics of PW. He presented a seven semester engineering course on photonics, which has just started in the academic year 2012/13. 60 students were recruited for this B.Sc. course. The photonic courses are present at WUT also at Faculties of Mechatronics (prof. M. Kujawińska) and WEiTI and in a few institutes like Telecommunications (optical fiber communications), IMiO (optoelectronic and photonic components, optical fibers, lasers, optical and photonic metrology), ISE (optical fiber functional components, optical fiber sensors, optical fiber Bragg gratings), IR (image optoelectronics and photonics). The didactic programs and curricula from photonics, optoelectronics, optics, and optical fiber technology were presented by several representatives form technical universities: Lublin (Institute of Electronics and nformation Technologies, prof. W. Wojcik), UMCS (Laboratory of Optical Fiber Technology, dr P. Mergo), Poznań (Chair of Telecommuniction and Optoelectronics, dr J. Lamperski), Silesian (Faculty of Electrical Engineering, prof. T. Pustelny), Wrocław (Faculty of Electronics, prof. E. Bereś-Pawlik), and others. Large research and didactic/teaching teams are active also at AGH in Kraków, Kraków Technical University, Białystok University of Technology (prof. J. Dorosz), UTP in Bydgoszcz, Kielce University of Technology, Gdańsk University of Technology. Optical fiber technology in this country at the research level is developing mainly at the universities. It is important to add to this development high level of teaching. The research work on optical fiber technology is considerably enhanced by numerous participation of B.Sc, M.Sc and Ph.D students.

XIV. Conclusions, Lublin-Nałęczów X 2012; Białystok-Białowieża I 2014

The conference on Optical Fibers and Their Applications, Nałęczów 2012 was a very fruitful and efficient meeting of the national research and technical, university – teaching, but also industrial and administration communities. There were presented numerable, valuable research results in the area of microstructural and plastic optical fibers. The ideas were exchanges on the subjects related optical fiber technologies. The development of national (and active in this geographical region) optical fiber laboratories – technological and metrological, was debated. The advances in photonics teaching at technical universities were compared between various institutions. Such a direct discussion between relevant sides has a value which can not be overestimated. Such a discussion has a positive impact on development of photonics in this region. Lublin meetings on optical fibers are always an occasion to remember the late prof. A. Waksmundzki, prof. J. Rayss and dr J. Wójcik – creators of the Optical Fiber Technology Center in Lublin at the UMCS. In agreement with the established conference cycle, the next meeting of the optical fiber and photonics research community is scheduled in Białystok and Białowieża, under the chairmanship of prof.J.Dorosz, in January 2014.

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